HIGH-TEMPERATURE SUPERCONDUCTIVE MAGNETS FOR SUSPENSION LEVITATION TRANSPORT SYSTEM

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***Abstract* - JSC NIIEFA has been developed combine electromagnetic suspension for magnet levitation transport system with permanent and normal conducting electromagnets, which operate with reduced electricity consumption [1].**

Keywords: magnet levitation transport system, superconducting magnet, current leads

I. INTRODUCTION

Permanent magnets (PM) known as bearing magnets, which are provide main carrying load of suspension. Normal conducting electromagnets (NCE) intended to control gap between levitation module and ferromagnetic guides as well as for sidemount stabilization. System with replacing of PM to superconducting magnets (SM) is consider to reduce dimensions of the suspension levitation as well as regulate the gap [2]. The advantages of applying SM against to PM are ability to range ascentional power by tapering current value and instead of normal magnets more significant reduction in energy consumption, weight and size characteristics in consequence of enhance current density in superconductive magnets [3] [4].

II. PRODUCTION OF SUPERCONDUCTION MAGNETS

Two superconducting magnets were made, assembled and tested for electromagnetic suspension in JSC NIIEFA. The SMs were made from second-generation high-temperature superconducting ribbon /wires/ (HTS-2). HTS-2 wire has width 12 mm and thickness 0.1 mm. Each magnet was spooled from fifty layers of superconducting wires.

Textolite used as material of coil structure with grinded grooves, which are specified for spooling HTS-2 and take-off diagnostic wires. After spooling superconducting coil has outer diameter 95 mm, internal diameter 78 mm, height 65 mm. After successful manufacturing each of magnets were tested in liquid nitrogen (as well in supercooled liquid nitrogen) and helium. The magnet's structure and SM are shown on Fig. 1 and Fig. 2.

Fig. 1. Magnet's skeleton.

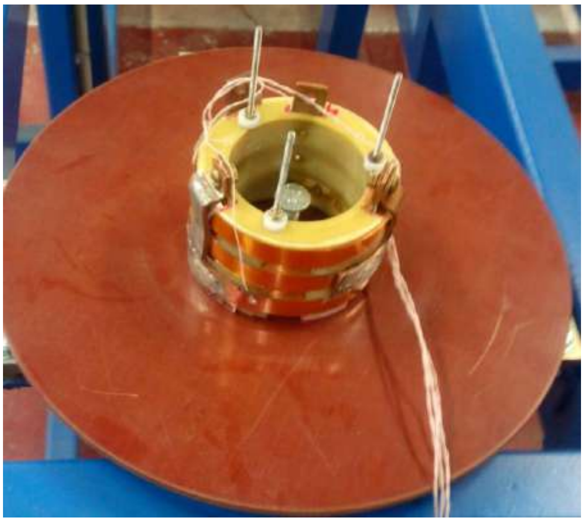

Fig. 2. Superconducting magnet.

III. CRYOGENIC SUPPLY SYSTEM

Superconducting magnets made from HTS-2, work at temperature of liquid nitrogen and lower. For this purpose two cryostats with SM developed and manufactured by personnel of JSC NIIEFA (Fig. 3).

Fig. 3. Cryostat with magnet

After placing SM in cryostat, was provided electrical retesting in liquid nitrogen (Fig. 4). Since the SM assembly required to control integrity of HTS-2 wire, therefore it was decided to carry out tests between each stage of assembling.

Fig. 4. Midline testing of SM

Cryostat with SM was installed on E-shaped core, which produced from Steel 10. Dimensions of core and cryostat are limited by electromagnetic suspension size. Thus superconducting magnet occupy almost volume of inner space. The gap between cryostat inner wall and SM is 4 mm, which filled with liquid nitrogen. Such size of cryostat not allow keeping SM during long time at temperature of 77 K without additional portion of liquid nitrogen. For this reason, special storage tank based on communicating vessels was developed and manufactured for feed liquid nitrogen in the cryostat. Cryostats and storage tank are connected by four flexible pipelines, two gas lines and two liquid lines, respectively. The level meter installed for monitoring liquid nitrogen level in storage tank. High-vacuum insulation applied to minimize heat transfer to cold zone. Cryostats, nitrogen storage tank and pipelines have a general vacuum jacket. The vacuum jacket evacuated to pressure $\leq 10^{-5}$ torr.

According to thermal calculation, total heat flux at temperature level of 77 K is 45 W, and 1 liter per hour of liquid nitrogen flow rate is required to maintaining work condition of superconducting magnet system.

The main heat transfer is radiate heat flux. Therefore, heat transfer from residual gas and construction elements was not taken into account [5]:

$$Q = q \cdot F = 55 \cdot 0.81 = 45\,W \quad (1)$$

where: $q = 55\, W/m^2$ - specific heat flow rate (300-80K), [6];

$F = 0.81\, m^2$ - total surface area of cryostats, nitrogen storage tank and pipelines.

Required amount of liquid nitrogen to maintaining the system at temperature level of 77 K:

$$M_{N2} = \frac{Q}{h_{N2}} = \frac{45}{199} = 0.22\, g/s = 1\, l/h \quad (2)$$

where: $Q = 45\,W$ - total heat flux at the temperature level of 80 K;

$h_{N2} = 199\, J/g$ - specific heat of nitrogen evaporation at p=1bar and T=77 K [7].

IV. CURRENT LEAD

System of current lead is containing superconducting current lead (SCL) and “dry” cryogenic current lead (CCL). The electric current goes to the superconducting magnet through this system.

Superconducting current leads made from two HTS-2 wires, which has width 4 mm and critical current 100 A. The SCL passed double current test at low temperature after manufacturing, then flexible pipeline installed inside and filled with liquid nitrogen (picture 5). In view of this, the temperature of SCL is constant (77 K).

Fig. 5. Pipeline with superconducting current lead

“Dry” cryogenic current leads used to transfer electrical current from the power supply sources to superconducting current leads and SM, which are located at room and liquid nitrogen temperature, respectively. To minimize heat transfer of liquid nitrogen storage tank is required to determine CCL optimal ratio of cross-section area and length. This ratio can be determined by following formula [8]:

$$LS = \frac{1}{I}\sqrt{2\cdot\int_{T_x}^{T_\Gamma}\frac{\lambda(T)}{\rho(T)}d(T)} = 25720\,{}^{1}\!/_{m} \quad (3)$$

where: $LS, {}^{1}\!/_{m}$ – ratio of cross-section area to length of CCL;

$I = 200\,A$ - ultimate /maximum/ operating current;

$\rho(T), \text{мОм}$ - specific electrical resistance of copper depending on temperature[6];

$\lambda(T), W/m\cdot K$ - thermal conductivity of copper depending on temperature [6].

$$LS = \frac{L}{S} = 25720\,{}^{1}\!/_{m} \quad (4)$$

where: L, m – length of CCl;

S, m² - cross-section area of CCL.

The CCL produced from copper rod (M1) with outer diameter 5 mm. Based on formula (4), optimal length of current lead is 0.514 m. Final assembly of system carry out on structure. Vacuum, cryogenic and electrical tests were carried out again. Fig. 6 shows pneumatic-hydraulic scheme of SM.

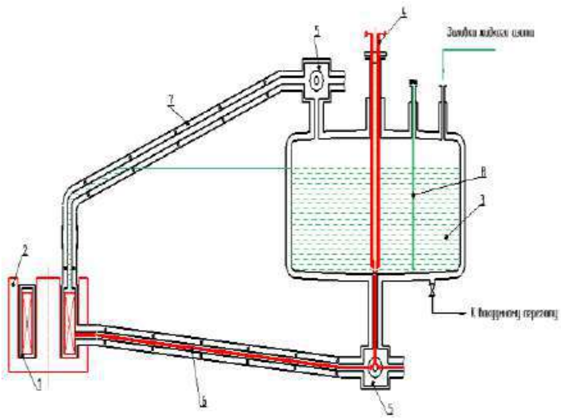

Fig. 6. Pneumatic-hydraulic scheme: 1 – cryostat with SM; 2 – E-shaped core; 3 – liquid nitrogen storage tank; 4 – CCL unit; 5 – collector; 6 – cryogenic liquid piping with SCL; 7 – cryogenic gas piping; 8 – liquid nitrogen level indicator.

V. MEASUREMENT SYSTEM

Test facility (Fig. 7) have been developed and produced for researching superconducting magnets characteristics such as critical current, value of magnetic strength and control over the transition to a normal state for suspension levitation transporting system in JSC NIIEFA.

Fig. 7. Test facility for superconducting magnets

The special control system was made for suspension and allowed to solve following problems:

-Clearance of gap;

-Measuring of voltage at HTSC coils for QUENCH detection;

-Platform position depending on loading and current at coils (value of magnetic strength);

-Measurement of current for stabilization platform position;

-Monitoring of SM lifting force.

Measuring control system consist of two gap sensors, modules of analog-to-digital converter (ADC), modules of digital-to-analog converter (DAC). Controller shows status of the system and regulating operation of the ADC and the DAC modules (Fig. 8).

Fig.8 Measuring control system

VI. CONCLUSION

The following goals have been drawn from the test results:

-Electromagnetic characteristics of the coil corresponds to the calculated data;

-Experimental data of nitrogen evaporation amounted to 1.1 liter per hour, thereby confirm accuracy of calculations;

-Development of methods to control and maintenance of the gap depending on loading levitating platform.

Nowadays, work is underway to produce a suspension of the magnet levitation transport system with reference constants and superconducting magnets.

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